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Biomimetic Geopolitics: The Earth, Inside Out

Elizabeth Johnson

The birthplace of the biomimetic “RoboLobster” was not what I expected. I had imagined small corner of a world of science fiction. Surely, a future in which autonomous robots crawled along seafloors would be imagined and produced amid ultra-modern laboratories and cutting-edge equipment. Instead, I found scientists who spent their days shuttling between a converted military barrack and damp and cluttered underground laboratories housed in the shell of a WWII bunker (Figure 1). The biomimetic future, it turned out, would be heavily conditioned by the past. The military sold off many of its coastal barracks and bunkers to universities and private corporations before the end of the Cold War. But while the presence of aquariums and laboratories suggested that the US military had abandoned these buildings, I found that its strategic vision was ever-present. Indeed, it was made manifest in the mimetic robots that scientists brought to life there.

A view of the weapons bunker, now transformed into a marine research laboratory

Credit: Elizabeth Johnson

1 This paper situates the birth of the RoboLobster within the wider shift in US military strategy known as the "biologic turn." In the late twentieth century the US Department of Defense (DoD) turned away from manipulating environmental conditions and human bodies in their strategies of spatial control. It instead turned toward scientific research into the bodies and behaviors of organisms themselves. This changed how the military institutions and scientists would understand the relationship among technologically-enhanced futures, environmental conditions, and biological organisms. In what follows, I detail that transformation to shed light on how the study of nonhuman organisms and the practice of biomimetic science have become relevant not only to engineers and innovators, but also as models of environmental adaptation and proxies for environmental knowledge.

Biomimicry and Environmental Epistemologies

Biomimeticists develop intimate knowledge of what evolutionary scientists consider the collective products of random mutations and natural selection—behaviors, bodies, and biological matters and secretions—for their capacity to inspire, to instruct, to make things that work. In a recent handbook on biomimetic innovation, engineers Tony Prescott, Nathan Lepora, and Paul Verschure argue that the field erodes the gap "between the natural and human-made" (Prescott *et al.* 2018). Social theorists have now long demonstrated that this "gap" is not ontological, but socially and historically constructed with practical and epistemological ramifications (Haraway 1984, Smith 1984, Latour 1993). Namely, the nature-society binary structures academic disciplines. It is also evident in the practices of colonial extraction and associated narratives of human exceptionalism and mastery. Biomimetic innovation is reshaping these epistemic traditions: disciplinary communities once distinct—biology, computer engineering, material science, and so on—are now sutured together in biomimetic design. And, while technological capacities leveraged over the past century enable us to see—and make use of—biological life at ever refined scales, it also elevates a growing menagerie of nonhuman organisms to the status of advisor to engineers and innovators. Flies are revalorized for the shape of their wings; geckos inspire 3M with their strategies of adhesion; sharkskin forms the basis of antimicrobial hospital material. Now, scientists, military strategists, engineers, and others can not only covet, but adopt, learn from, and listen to the various *techne* of other organisms as never before.

2 By exploring how evolution "succeeded" thousands if not millions of years before our time, innovators not only develop novel products of technological development; they reinvent processes and ways of knowing. As Sophia Roosth has written in the context of her work on synthetic biology, emerging fields that unite bioscience with engineering make "analyses of life newly simultaneous with and enabled by synthesized instantiations of it" (Roosth 2017: 8). Through the emergence of these new fields, the language and ideology of production inflects the biosciences just as biology becomes the basis for productive technologies. Accordingly, biology can no longer be viewed as foundational to biotechnological constructions. The gap between what is "natural" and "human-made" is thus not breached—as Latour (1993) has argued, these spheres have in practice been fully integrated—but rendered insensible. Accordingly, long-held distinctions among raw materials, technological tools, and products of innovation are similarly thrown into confusion. In the process, the epistemic cultures of bioscience and technological innovation have become recursively entwined.

3 Roosth situates these laboratory transformations amid the wider socio-political milieu of late capitalism. Bioscience—including its objects of study and construction—develops along a path of capitalist valorization. Charting how bioscience produces knowledge as part of the reproduction of capital has been the remit of science and technology studies scholars for decades now. Through the theorization of biocapital, biovalue, lively capital, and encounter value scholars have engaged with Marxist historical materialisms to trace the multi-directional recursive tendencies between epistemologies, production, and the reproduction of life (see, for example, Rajan 2006, Haraway 2007, Helmreich 2008, Rajan 2012, Dumit 2012, Waldby 2019). The framework of capitalism helps to ground and explain the recursive techno-bio productions emergent in our recent world. It also helps STS scholars and others prognosticate on the direction of emerging and future bio-technologies.

4 Of course, capitalism names only one of several material and social histories that co-produce the epistemic cultures and trajectories of contemporary bioscientific practices. Patriarchy, colonialism, militarism, petroleum extraction, and racism intersect with privatization and accumulation at both past and current conjunctures of biological life and technological innovation. Attending to these historical contexts brings into relief different threads of bio- and technological production, offering ground for a different set of concepts and considerations. In what follows, I focus on biomimicry's military history to offer another perspective on the recursive breakdown between biological knowledge production, technological innovation and wider material environments. Rather than biocapital, we might understand these transformations through a lens of bio-operability and eco-securitization.

5 In the fall of 2009, I spent four months shuttling between the aforementioned barrack and bunker, shadowing a team of researchers studying the neuroethology of marine invertebrates to build biomimetic robots. The so-called RoboLobster—and the wider field of biomimicry—emerged out of military strategy to change not only how biological knowledge and technological productions entwine, but how both are also tied to transformations in understandings of the environment. The rise of biomimicry is typically attributed to the drive for environmentally sustainable, nature-based solutions to design problems. But the US Department of Defense (DoD) has played a much more significant role in the field's development and legitimation than any environmental or design movement. Nevertheless, the DoD's approach to biomimetic technology produces environmental knowledge. Here, however, the environment is not that which requires salvation, but that to which we must adapt in order to survive.

6 The RoboLobster project is emblematic of wider changes in the role of the biosciences in the US military's strategic landscape throughout the twentieth century. It was the product of strategists, particularly at the Defense Advanced Research Projects Agency (DARPA), who looked to the survival of nonhuman organisms for technological inspiration. This was part of a wider "biological turn" in US DoD strategy. This "turn" I suggest relocated the study of earth and environment within nonhuman bodies. In doing so, it created opportunities to attune to environmental threats through the internal operability of organisms. I consider how military biomimetics orients certain perspectives on nonhuman biologies, reframing them not only as active elements in political strategy, but also recoding their life activities through the language of productive attributes and identifying a suite of behaviors that become worthy of imitation. This process, I further suggest, reconceptualizes bioscience and its labors as productive assets in an effort to make environments operational.

From Battlefield Environment to Organism: The Biological Turn

For much of the twentieth century, warfare was won and lost through the manipulation —or annihilation—of environmental conditions for tactical gain. On battlefields, disciplined bodies dealt in and were made subject to death (Foucault 1995, Wilcox 2015). And as soldiers were made to bend to the difficult conditions of warfare, knowledge regimes and technologies attempted to bend environments to better suit the sustenance—or, alternately, the destruction—of bodies. Parroting Deb Cowan, a "deadly life of logistics" transformed the earth by making land operational, optimizable, workable for the execution of state violence (Cowen 2014).[1]

7 As part of this logic of classic, territorial warfare, the US military acquired and transformed coastlines to deter invasion beginning in 1898 with the Spanish-American War. Throughout the twentieth century, those same lands would be transformed in accordance with the development of weapons technology of the time. During WWI they would house submarine stations. In the second World War, the military raised gun turrets. These would later become Nike missile launchers. By the middle of the Cold War in the 1960s, this mode of coastal defense was already waning. Seaside bunkers and barracks were deemed no longer of strategic import and were decommissioned. Some lay abandoned, while others were repurposed and sold to public and private universities for laboratory research. In the bunkers where I conducted my research,

ammunition and missiles had been replaced with collections of whalebones and makeshift aquaria filled with lobsters, crayfish, and other marine animals. While the transformation of this site from barrack and bunker to laboratories and classrooms appears as a demilitarization of the coast, the transition of this site maps onto a wider respatialization of warfare from territory into the bodies of organisms.

8 Animal bodies have long been part of regimes of warfare, whether ridden into battle or made experimental subjects of military technologies (See, for example, Mayor 2003, Forsyth 2017). And, as Jake Kosek has written, the figure of the animal and division between humans and nonhuman are an intimate "part of the discursive terrain on which certain bodies are made killable and others are celebrated as super human" (Kosek 2010: 670, see also Agamben 2004, Shukin 2009, Chen 2012). Throughout much of the twentieth century, military investments in the biosciences were focused primarily on experiments designed to either enhance human bodies in efforts to expand the capacities of allied warfighters or to incapacitate enemies.[2] Since WWI, nonhuman life has been made to play a supporting role in these efforts. Alongside the expanding pharmaceutical and chemical science sectors, the military made use of rabbits, rats, pigs, and other organisms as test subjects in the development of technologies, food science, and pharmaceuticals. In government laboratories, their bodies would be used to identify the boundary between life and death in a growing chemical and biological pharmakon (see, for example, Figure 2). As Joseph Masco has written in the context of US nuclear testing, the human body's susceptibility to damage was prefigured by "the vaporized, mutilated, and traumatized animal body" (Masco 2004: 529).

Hanford scientists feeding radioactive food to sheep Hanford, WA.

Credit: U.S. Department of Energy. Public Domain

9 In the post-Cold War period, nonhuman bodies continue to be employed in these roles, but animal life—and, more precisely, biological life—now performs other functions as

well. Beginning in the late 1980s, bioscience research began inspiring technological development as part of a “biological turn” in military strategy. This “turn” has drawn nonhuman animals onto the terrain of military engagement in new ways, in part seeding the fields of biomimicry and biosensing. Amid efforts to make inaccessible environments operational, optimizable, and workable, they transformed how scientists and strategists view the relationship between life and environment. Beginning in the late 1980s various branches of the US military—most notably the Office of Naval Research (ONR) and the Defense Advanced Research Projects Agency (DARPA)—experimented with bioscience research as a strategy for solving vexing military problems. Accordingly, animal life began to figure differently in the context of military science: DARPA’s program managers in particular began to reimagine how DARPA’s “strategy for high risk investments” might be applied across “a breadth of life science applications” (personal communication, former DARPA program manager, 2009). According to a key DARPA program director, Alan Rudolph, investments in the biosciences were motivated not by a desire to control biology, but rather to capture “materials, structures and mechanical performance [that] could lead to new defense capabilities” and enhance soldiers’ performance on the battlefield (Rudolph 1999, quoted in Ackerman, 2000).

10 It is with this vision in mind that Rudolph led DARPA to invest in technologies that “would move based on how cockroaches move, that would fly based on how bumblebees fly, that would climb walls based on how geckos climb walls” (Junod 2003). Because no one knew how these creatures did what they do, Rudolph used DARPA funding to seed research across industry and the academy. Multiple projects at publicly and tuition-funded institutions would go on to pursue exactly those questions. Researchers at UC Berkeley and Case Western Reserve investigated the movement of cockroaches; biologists at the University of Oregon finally determined how geckos stick to walls; and mechanical engineers collaborated with biologists at CalTech and Stanford to understand fruit fly flight. All of these programs in bioscience research have contributed to the development of military technologies. Among them are DARPA’s Z-Man suit, which enables soldiers to scale walls; exo-skeletons for carrying loads; micro-drone technologies; and multiple biomimetic robots, including the RoboLobster.

11 We might understand this desire to capture the performance capacities of nonhuman organisms as driven by an impulse to extend and overcome the limitations of both human bodies and minds. But it is also driven by a strategic perspective on environmental conditions--one that transforms all environments into battlefields and nonhuman behaviors into a warlike struggle for survival. As Rudolph remarked in an interview in 2003, soldiers on a battlefield are required to “sense changes in their environment” in order to “adapt and survive” (Junod 2003). In this way, Rudolph explained, soldiers are like—*and could become more like*—cockroaches as “all [cockroaches] do is adapt and survive” (*ibid.*). In the next section, I take readers into the lobster and its robotic counterpart to examine how environments are rendered workable through study of the bodies that inhabit them. But I also amplify how these internal capacities of organisms become vehicles of knowledge about and manipulation of hostile and unpredictable environments.

Into the Lobster, Into the Littoral

Through the eyes of the US military, the ocean appears as what strategists refer to as "vast sanctuaries" for potentially emergent threats. Most notable among these threats are underwater mines. Mines stymie movement, paralyzing forces and threatening the acquisition of provisions. The development of mine countermeasures (MCM) has therefore been a priority for the US Navy since the Korean War in the early 1950s, when underwater mines damaged ten naval vessels. Since 1959, the US Navy has enrolled nonhuman animals, primarily sealions and dolphins, in mine clearance efforts (Figure 3). Marine mammals can do what humans cannot: spend long periods under water, echolocate, and access a suite of sensory capacities unavailable to humans. They are highly valued for their ability to expand the U.S. military's capacity to navigate the ocean subsurface to recover underwater mines, guard assets, and perform reconnaissance.[3] These animals are effective for both mine reconnaissance and clearance in deep water. But they require Navy personnel to execute mine detonation, making them only minimally effective—and potentially lethal to humans and animals alike—in the challenging environment of the littoral.

A U.S. Navy Marine Mammal Program dolphin, fitted with a location device, who performed mine clearance in the Persian Gulf during the Iraq War.

Credit: U.S. Navy photo by Brien Aho. Public Domain.

12 The scientific shorthand for the littoral zone of the ocean is "hydro-dynamic." Beneath the surface, patterned wind-generated waves meet the moving topography of land, producing largely unpredictable "small-scale turbulence, larger-scale coherent vortical motions, low-frequency waves, and steady flows" (Battjes 1988: 257). Anyone who has swam or surfed at the seaside on a day when the wind and waves are high has likely experienced these "stability problems" firsthand. Human bodies are not well suited to

this space of turbulence. While some may play in the surf on surf boards and inflatables, working within it is another matter altogether. As an article on “surf zone technology” in U.S. Navy publication *Surface Warfare* explains, “The wave action, currents and rapid change in the surf zone make it a difficult operating environment. The turbidity, bubble content and acoustic noise in the water combine to make a very difficult sensing environment” (Crute 1998: 35). In short, the littoral creates challenging conditions for the production of “battlespace knowledge” (Naval Doctrine Command 1998: 29). Visual, aural, and operational capacities are all compromised in this environment.

13 Lobsters have a long, low shape and wedge-like posture (Figure 4). These physiological traits help to hold its body to the sea floor amid intense current. They can position their claws, abdomen, and swimmerets relative to the movement of the sea; their eight legs end in sharp points, pinching into the seabed, maintaining traction in the surf and providing stability. According to neuroethologist Joseph Ayers, their body structure allows them to navigate the volatile environment “with impunity” (Ayers 2004: 347). Thus, the lobsters’ talent in movement was perceived and studied anew, considered a strong model in the pursuit of something “that can stand up to the harsh environment of the littoral zone” (personal communication, former DARPA program manager, 2009). In the early 1990s, the Office of Naval Research (ONR) reached out to Ayers about the potential of harnessing actual lobsters in the detection of underwater mines. Ayers “naively” replied that “it would be easier to build a lobster robot” (Ayers, quoted in Taubes 2000 : 80).

An American Lobster, *Homarus americanus*, on the seafloor off the coast of New England.

Credit: U.S. Geologic Survey, Public Domain.

14 RoboLobster was thus born with the aid of modest grants from the ONR and developed with funding from DARPA. It remains one of its most widely publicized products. The

robot was built with the same low-splayed posture as the real lobsters living in Ayers's laboratory. Ayers describes it as an "8-legged ambulatory vehicle" with an eight by five-inch body design capable of mimicking the lobster's capacity for omnidirectional walking. It has a tail and "claws" to provide hydrodynamic stability (Figure 5). And it is programmed with what is referred as a "behavioral library" that mimics the degrees of freedom in movement expressed by living lobster bodies (Ayers and Witting 2007: 285). In a feature on "Warbots" on the Military Channel, Ayers described the Navy's vision for what RoboLobster could do. By navigating the harsh environment of the littoral, the RoboLobster could be directed to "march up to the mine, park on the mine, and then be sent a sonar signal to arm itself and detonate the mine" (Warbots 2008). From the perspective of this purpose, the value of the RoboLobster is that it could be mass-produced at a low cost. In sharp contrast to the lives of soldiers and dolphins, it would be expendable.

RoboLobster, version 3.1.

Credit: Elizabeth Johnson

15 Today, the robot remains in the prototype stage. Neither the US DoD nor anyone else has mass-produced or deployed it in conflict zones around the world. It is not utilized as part of mine countermeasures, nor does it function in the littoral in any operational capacity. Its true contribution lies in its proof of concept and how it transformed the DoD strategic imaginary, advancing biomimetic technology in the process. To appreciate how the RoboLobster instituted a paradigm shift in biological and environmental engagement, it is essential to understand the details of its construction.

16 The RoboLobster prototype is semi-autonomous. It receives commands for large-scale behavior, such as walking direction, via a laptop or microcontroller that runs a prescribed series of movements. But a biomimetic exteroceptive suite—including a compass, pitch and roll inclinometers that measure the body's position in reference to

the ground, antennae that respond to current, collision, and other mechanical stimuli, and bump sensors embedded in the "claws"—enables a certain amount of autonomous decision-making. These components correspond to behavioral sequences appropriate to the dynamic environment in which lobsters might find themselves. For example, if the antennae sense an increase in the rate of water flow, the robot will lower its body, depress its claws, reorient its direction to face the current, pitch the hull forward, and elevate its tail. Along with bump sensors, this gives the robot the capacity to make basic decisions regarding tactile navigation.

17 While impressive, these capacities alone do not make the RoboLobster unique. Even the most basic robotic devices are programmed to respond to sensory inputs and behave in relation to environmental stimuli. Most robots cannot, however, learn to adapt to their surroundings. Conventional machinery operates with algorithmic "artificial intelligence," working via a pre-programmed suite of behaviors, like those of the RoboLobster listed above. The code performs well in the limited and immobile environment of a software platform or certain laboratory conditions where the programmer can anticipate the field of activity. But the structure of algorithmic programming ensures that robots can only learn to respond to conditions that their programmers anticipate. Like Borges' map that stretches to the extent of its territorial empire, to anticipate change—or differentiation—in an environment, an algorithmic machine must carry all known aspects of that environment with it at all times. The complexity of the lived environment means that a programmer cannot anticipate every "environmental contingency" that the robot will encounter (Ayers and Witting 2007: 288). To successfully program the RoboLobster through such a model, it would be necessary for the code to understand hydrodynamic flow in the surf zone. This is a dizzying proposition.

18 Rather than attempt to program a robot for the environment it would encounter, Ayers insists that we ought to consider the lobster even more closely, to understand not only its body plan or its patterns of movements and behavior, but to intimately know how such an organism works. Creating a robot that navigates the surf zone as a lobster does, he argued, was impossible without mapping the internal chemical reactions that guide and produce lobster bodies and behaviors. Rather than simply understand how it moves, he therefore studied how it comes to initiate movement. That is, to navigate the surf zone "with impunity," one needs to begin inside out, with the lobster's own programming architecture. By reverse engineering a lobster's nervous systems, Ayers attempted to build a technological device that, like life, can "adapt and survive" even in unexpected encounters.

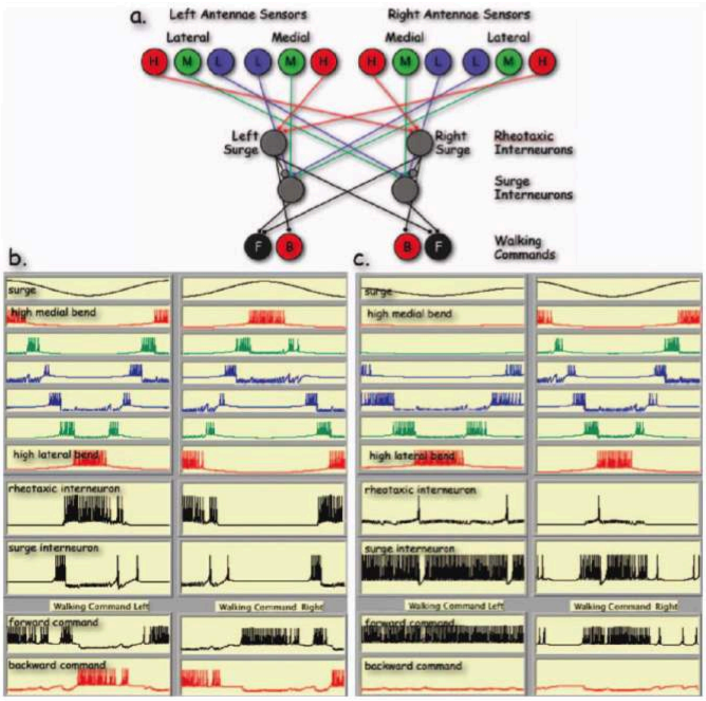
19 Understanding the neurological systems of a lobster is no simple task.[4] Ayers has worked to record and map the neuroresponses of lobsters since the late 1960s, advancing knowledge about their locomotive systems and how they overcome challenges associated with living in a hydrodynamic environment. To that end, he designed numerous experiments that explored the relationship between limb movements, body position, and neuronal circuits. He planted electrodes in live lobsters to record the firing patterns of motor neurons (Figure 6). With time-sequenced film of lobsters on the treadmill, he matched the electronic activity in their neurons to the rhythm of movement in the lobster's gait. After a series of experiments, he was able to define the animal's degrees of freedom and map the neural pathways that corresponded to muscle movements in actual lobsters.

Lobster Experimentation.

Credit: Elizabeth Johnson

20 A model of the lobster’s neural network takes the form of a complex diagram of circuits. Looking like a detailed flow chart, the diagram matches neuronal excitations with lobster behavior (displayed in Figure 7).[5] From this diagram, Ayers constructed an “electronic nervous system.” In this device, a series of on/off switches stand in for neurons. By turning them off or on in a pattern that mimics the lobster’s own neural network, they generate a “response” (in this case a digital output) that represents the inhibition or excitement of muscles in accordance with the observed patterns of lobsters. This electronically modeled mockup of the architecture of the lobster’s nervous system sits in Ayers’s laboratory, comprising a collection of wires and nodes on a platform that connects to a computer interface serving as the system’s central pattern generator (CPG). The electronic nervous system represents the inside of the RoboLobster, a disembodied CPG that issues commands which register the effects of lobster movement on a computer screen.

A map of the neurological patterns of lobster movement.



Source: Ayers, Joseph *et al.* "Controlling underwater robots with electronic nervous systems." (2010)

21 Ayers embedded this electronic nervous system into the "biomorphic plant" that would become RoboLobster. The "neurological" circuit-based controller receives and sends informational signals based on a system of four interneurons that mimic its step cycle in a way that is directly consonant with scientific understandings of the lobster's nervous system (Ayers and Witting 2007: 279). In this way, RoboLobster maintains the same "stability in the environment" that lobsters enjoy (Ayers *et al.* 2000: 2).

22 Finally—and most significantly—RoboLobster carries within its biomimetic CPG what Ayers considers one of the single most important traits shared across all forms of life in possession of a nervous system. It is the trait that, he insists, confers on organisms their capacity to learn, the very basis for individual adaptation to environmental conditions. Ayers refers to this innate and internal capacity as chaos. Early recordings of isolated lobster neurons show what he calls "clear regimes of chaotic activity" (personal communication, 2009). He identifies this chaotic firing of individual and networked neurons as central to solving the everyday problems faced by biological systems as they move through the environment. These patterns of chaos expressed in the nervous system are one way in which animals discover new behaviors, new combinations of movement, and new ways of employing their bodies in response to unanticipated environmental constraints and opportunities.

23 Animals encountering unknown environmental obstacles, particularly those that confine bodies, often quickly find that practiced patterns of movement and behavior fail to achieve the desired freedom from constraint. In response to such confining conditions the subsequent behavior—expressed by animals and humans alike—is to squirm. By implementing the ability to exhibit squirming, an ambulatory robot can wiggle its way out of a tight spot and learn to place its body in wholly novel comportments. In this valorization of squirming, the lobster becomes recognized for a

new talent, valued not only for its ability to navigate a difficult environment, but its capacity to engage with the unexpected within it, to maneuver within environmental conditions that it cannot foresee.

24 Ayers worked with the University of California Institute for Nonlinear Dynamics (now part of the UCSD Biocircuits Institute) to incorporate these chaotic patterning circuits into the RoboLobster's electronic nervous system. These patterns of variability give the robot the flexibility to adjust its gait to irregularities on the sea floor while still maintaining stability. More so, however, they promise to extend the capacities of the robot's biomorphic form through its interaction with the environment. As Ayers noted in an interview in 2015, "the beauty of these electronic neurons is they have 'variable chaos.' Our larger goal here is to start building these controllers with variable chaos, to see if we can get the robots to wiggle and squirm like the real animals" (Ayers, quoted in Faggella 2015). Thus, like all living bodies, RoboLobster promises to be more than an expression of its preprogrammed "code." Twisting Spinoza's famous provocation, Ayers's RoboLobster does not yet know what it can do. Neither, as it turns out, do we.

25 The RoboLobster's legacy lives on in the wider field of military technoscience. In more recent programs and strategic documents of the Navy and DARPA, autonomous robotic devices capable of crawling on the sea floor continue to figure as crucial components in their visions of future warfare technologies. And their quest to appropriate biological intelligence has only intensified. Most recently, their Persistent Aquatic Living Sensor program funds research on underwater organisms whose sensory capacities might be tapped directly as signals of environmental change.

Out of the Lobster and Into the Sea: Turning the Earth Inside Out

The US military's "biological turn" has given rise to an emergent epistemology in which environmental conditions might be known through the inner workings of organisms rather than the manipulation of environments. Biomimetic techniques—and the ecological and biological knowledge of which they are a part—become "battlespace knowledge." Bioscience therefore becomes a proxy for knowledge about the environment-cum-battlefield. Lobsters here are not the passive subjects of manipulation, but their bodies are made active participants capable of inventing and reinventing technology and themselves within a process of earthly experimentation. The RoboLobster therefore appropriates inventive capacities of lobster life in an attempt not to master the littoral, but to create bodies that can go to work within it. Here, internal and external are reconfigured, as scientists reproduce the inner workings of bodies to make knowable the outer dynamics of environmental conditions: the robot renders the hydro-dynamic environment workable from the inside out.

26 It is tempting to read this relationship between military science and nonhuman life as evidence of nature's continued domination. Paul Virilio warns of this danger directly. In his writing on military science, he cautions against the acceleration of knowledge forms that are solely in the service of innovation and production. Such a science, he writes, is not "for itself," but rather enslaved, born of a "fatal confusion between the operational instrument and exploratory research" (Virilio 2005: 1). Following Virilio, we might worry over the remaking of environments as battlefields and life as "metabolic bodies," valued each not for what they were, but for what effects they can

produce. We might see the Robolobster and the neurological experiments that made it as a form of "endocolonization", as inside and outside are inverted and specific biological capacities eclipse the study of organisms and ecosystems. Such a science, Virilio writes, threatens to make a "world without intimacy" that would become "alien and obscene, entirely given over to information technologies and the over-exposure of detail" (Virilio 2005: 57).

27 Such a narrative is compelling. These emerging investments of biological life *are* a form of epistemic colonialism, but Virilio's critique is misplaced here. After all, Ayers built his career on an attempt to make the alien bodies and brains of lobsters not obscene or even exposed, but intimately understood. In interviews and writing, Ayers often speaks of his love of lobsters (as well as many of the other sea creatures in his laboratory). While confessions of love cannot be taken at face value—particularly when they require experimenting with the very objects of love—the DoD's strategy in executing the biologic turn invested in that intimacy. The effect is an expanded capacity to know life's diversity, its abundance, its chaotic capacity for transformation. Such knowledge practices are not built on the back of biomaterial extraction (although that continues apace in other areas), but technological inspiration. Such innovations thus do not threaten to reduce or exhaust biological life. Rather they amplify, fetishize, and reorganize its superabundance and capacity for differentiation. Mastery and logics of command and control recede here (even as they persist elsewhere). In their place, the military attempts to build itself a more adaptive technology on the back of multi-species engagements in the world. This approach to the amplification of life's superabundance is part of a revisioning of environments as well as a technological fix for hostile or inconvenient environmental conditions. Knowledge of the neurological workings of the lobster enhances human capacities to operate within what are considered the "hostile" environmental conditions of the littoral zone. Biomimetic techniques build "battlespace knowledge" through bioscience. They remake the inner workings of organisms as proxies for knowledge about the environment itself. The robot stands in as the objectification of an organism as well as the ocean environment in which it lives.

28 Through this lens, biological bodies become valued for their capacity to work. Through a language of operability, analyses of life are made synonymous with capacities to adapt to environmental conditions. In the process, not only have the epistemic cultures of bioscience and technological innovation become recursively entwined, they are enfolded within a view of the earth prefigured as a battlefield and its inhabitants viewed as active agents of transformative potential on it. These transformative potentials are not driven by accumulation, but by a logic of the operational dominance over space and environmental conditions. Rather than biocapital or biovalue, they twin bio-operability together with eco-securitization.

29 What, then, makes the earth into a battlefield? Or, put differently, where do we locate the making of contemporary warfare? In these technological strategies, it is found not only in the spaces of violent conflict or infrastructures of national defense; it is also prefigured in laboratories of knowledge production. In the concluding section, I consider how these dreams of biologically enhanced warfare alter how human and nonhuman lives (rather than life as such) are composed in relation to biologies, environmental conditions, and the labor of knowledge production.

A Nonhuman Geopolitics?

The US military's "biological turn" has given rise to an emergent epistemology in which environmental conditions might be known through the inner workings of organisms rather than the manipulation of environments. Through biomimetic techniques, "battlespace knowledge" has been channeled through bioscience, where the inner workings of organisms become proxies for knowledge about the environment itself. Lobsters here are not the passive subjects of manipulation, but their bodies are made active participants capable of inventing and reinventing technology (and, indeed, themselves) within a process of earthly experimentation. The RoboLobster therefore appropriates inventive capacities of lobster life in an attempt not to master the littoral, but to create bodies that can go to work within it. Here, internal and external are reconfigured, as scientists study the inner workings of bodies to know the outer dynamics of environmental conditions.

30 In his work on aerial drones, Ian Shaw has argued that autonomous weapons serve the interests not of a people or of a population's health, but those of a world that is "predominantly nonhuman" (Shaw 2016: 39). Just as manufacturing has replaced human labor with machines, the DoD technologies promise to eliminate human life not only from the ranks of enemy forces, but from the US's own front lines of warfighting. Technologies and advanced weaponry as well as techniques of biomimicry have made it ever easier to distance bodies from battlefields, an outcome of changing public perceptions of warfare particularly in the post-Vietnam era. While the number of military personnel is less than half of what it was in 1955 (currently 1.3 million active duty), the biologic and technological turn of the US military has enabled "force multiplication." Additionally, for Shaw, the military's strategic imaginary is more concerned with maintaining flows of commerce and capital rather than historic or humanitarian goals. Following this trajectory, we might envision that the RoboLobster —and the military's engagements with the fields of biomimicry more widely—further accelerates this transition toward a "nonhuman" geopolitics. Creating robots with the capacity not only to act autonomously, but to learn autonomously using biologic intelligence and act in a conflict environment seems to create an ever-further distance between humans and the politics of warfare.

31 These creations and events certainly redistribute how we understand causality between human, animal, and machinic actions on the battlefield. However, much like territory, human action does not disappear in these experimental practices—and we can scarcely consider them nonhuman. Rather, humans are elsewhere in both time and space. Through the crafting of bioscience, biomimetic machinic warfare imaginaries recondition the labor of war, reshaping what we know and how we engage with environments. If, as Louise Amoore has written, who we are flows into the algorithms that govern autonomous technologies, the *where* of geopolitical conflict is also displaced into the epistemic cultures that come to know biological life (Amoore 2017).

32 This changing atlas of war—distributed among technological and biological capacities—finds the DoD's most crucial sites of engagement not on the coast, but in laboratories of research and development, where biomimetic projects are imagined and put into production. The battlefield is thus not only where technologies are used, but also where they are produced. In the process and as Louise Amoore and Rita Raley (2017) have noted, the military's technological programs shift responsibility away from soldiers and

into experimental programming carried out by civilians, researchers, the archives of science and engineering, and, in this case, biological lifeforms. By displacing responsibility not only into technology, but into the biosciences, biomimicry threatens to naturalize the parameters of survival in geopolitical and biopolitical engagement across space and time. Bioscience becomes warfare by other means. In doing so, it occludes geopolitical violence and domination by reducing warfare to questions of operability. In the process, the intellectual labor of the biosciences becomes recursively entwined with a militarized epistemology. In this case, it is one that reimagines the earth as a solution space and life as a proxy for it. The conceptual terrain that emerges at the crossroads of biological life and political power is not attached to organisms or nature as such, nor to the human animal divide. Rather it is one in which humans, nonhumans, and environments have come to be imagined and navigated in an attempt to render all three *workable* through the amplification of life's diversification. Accordingly, it is not quite accurate to say that the littoral zone is viewed through the body of the lobster, but that both lobster and littoral are caught together amid a militarized landscape, rendered operable in certain suite of capacities.

33 The geopolitical imaginary and its biopolitical realities make lobsters available to technology through an understanding of the environment as both hostile and, ultimately, operable. It makes us available to an environment that is understood and known through the capacity for operation, for work, for productive capacities. Possible becomings between human, animal and environment are placed onto this terrain of operability. Ayers's work brings our attention to how the world passes through bodies, creating them, as well as their conditions of possibility. The world that we come to share is one that is glimpsed and made through the problems of the US military; the world under the waves becomes one of mines and combat and lobsters, an environment of frictions and possibilities for claiming space. Mapping these arrangements and technologies reveals that sites of experimentation—distributed across the US and the world—are where we might begin to articulate the world and its inhabitants differently. What might life's superabundant and multiform capacities engender if they were called to participate not on battlefields, but in the constitution of a multi-species common?

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NOTES

1. This has also been a key theme in Matthew Farish's work on US Cold War experiments in the Arctic. His work has detailed how military science experimented on human and animal bodies in the Northern latitudes so that bodies might be optimized for warfare against the Soviet Union.
2. If experiments failed to enhance the capacities of U.S. soldiers, researchers were often encouraged to see if the results could be used to incapacitate enemies (see Marks 1991). This experimental landscape is part of the radicalized and classist history of state-sponsored research in the twentieth century. It also reflected and benefitted from the horrific experimental practices of the Nazis during WWII that came to light during the Nuremburg Trials.
3. The Navy transported several dolphins to the Persian Gulf during the Iraq War to clear the harbor of Umm Qasr. This was the first war-time mission executed by the Navy's Marine Mammal Program.
4. It is important to note the difference here between neurology and neuroethology. The former is primarily concerned with exploring neurological systems on the molecular scale, like the sodium-potassium pump that I have just described. While neuroethology is concerned with the same molecules, it is also committed to connecting their behavior with that of the larger organism.

5. Crafting an electronic nervous system is a direct extension of the way that neurological science has long understood the subjects of its research in machinic terms. By most accounts, the best analogy for understanding how neurons work is an alkaline battery. Neuroscientists describe the mechanism that triggers action potentials in neurons as a sodium-potassium (Na+K+) pump, a system which, when pared down to its most basic elements, seems to work with mindless simplicity. As basic neuroscience textbooks describe it, a neuron at rest is polarized. With a distribution of potassium (K+), sodium (Na+), chloride (Cl-), and protein (A-) ions within and outside of the cell, it maintains a negative charge on the inside in relation to its immediate environment. The Na+K+ pump maintains that polarization by actively selectively only certain ions to pass through its membrane. For every three sodium ions that the membrane moves out of the cell, it opens channels to allow two potassium ions to travel inside, resulting in a sustained imbalance between the number of potassium ions inside relative to sodium ions. This continual movement of positive and negative ions creates a negative electric charge known as the neuron's "resting potential." Stimulation causes channels in the membrane to open, allowing Na+ atoms outside of the cell to rush in. This onslaught of positively charged ions reverses the polarity of the cell momentarily, before openings in the membrane return the distribution of ions back to the resting state. This momentary disruption causes an action potential to fire—an electric impulse that elicits movement in the case of motor neurons and sensation via sensory neurons.

ABSTRACTS

This paper analyzes how biomimetic innovations reveal a recursive knot between biological knowledge production, technological innovation, and wider material environments and histories. It focuses on the so-called RoboLobster project and the role of biomimetic technology within US military strategy. I consider how military biomimetics orients certain perspectives on nonhuman biologies, reframing them not only as active elements in political strategy, but also recoding their life activities through the language of operability. This, I suggest reconceptualizes bioscience and its labors as productive assets through a lens of bio-operability and eco-securitization. Through a language of operability, analyses of life are made synonymous with capacities to adapt to environmental conditions. In the process, not only have the epistemic cultures of bioscience and technological innovation become recursively entwined, they are enfolded within a view of the earth prefigured as a battlefield and its inhabitants viewed as active agents of transformative potential on it. These transformative potentials are not driven by accumulation, but by a logic of the operational dominance over space and environmental conditions.

Une géopolitique biomimétique. Placer l'extérieur à l'intérieur
Les innovations de la biomimétique ont mis au jour un lien récursif entre la production de savoirs biologiques, l'innovation technique et le contexte plus large des histoires et des environnements matériels. Cet article examine le projet RoboLobster et le rôle de la technique biomimétique dans la stratégie militaire des États-Unis. De quelle manière le biomimétisme militaire oriente-t-il certaines perceptions des biologies non humaines, en mettant ces dernières au service d'une stratégie politique, mais aussi en recodant leurs activités vitales à travers un langage de l'opérabilité ? La biologie et sa pratique sont re-conceptualisées au prisme de la bio-opérabilité et de l'éco-sécurisation pour devenir des actifs productifs. Par le langage de l'opérabilité, le vivant

devient synonyme d'une capacité à s'adapter à des conditions environnementales. La culture épistémique de la biologie et celle de l'innovation technique se trouvent ainsi étroitement liées dans un rapport récursif, mais aussi inscrites dans une vision de la Terre comme champ de bataille, et de ses habitants comme agents actifs doués d'un potentiel transformatif. Ce projet n'est pas motivé par un souci d'accumulation, mais plutôt par une logique de domination opérationnelle de l'espace et des conditions environnementales.

INDEX

Mots-clés: sécurité, géopolitique, environnement, militarisation, neuroéthologie, bio-opérabilité
Keywords: Security, Geopolitics, Environment, Militarization, Neuroethology, Bio-Operability

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